

FORM PTO-1390 (Modified)  
(REV 10-95)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371

9847-0049-6X PCT *PCT 4*

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

09/554884

INTERNATIONAL APPLICATION NO.  
PCT/SE98/02162INTERNATIONAL FILING DATE  
27 NOVEMBER 1998PRIORITY DATE CLAIMED  
27 NOVEMBER 1997

## TITLE OF INVENTION

A METHOD OF APPLYING A TUBE MEMBER IN A STATOR SLOT IN A ROTATING ELECTRICAL MACHINE

APPLICANT(S) FOR DO/EO/US

Bertil LARSSON, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☒ has been transmitted by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
- ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☐ have been transmitted by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

## Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.  
A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report  
Notice of Priority  
Marked-up Copy of Specification  
Form PTO-1449  
Response to Petition Under 37 Under CFR 1.182  
List of Related Cases

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR <b>09/554884</b> )	INTERNATIONAL APPLICATION NO. <b>PCT/SE98/02162</b>	ATTORNEY'S DOCKET NUMBER <b>9847-0049-6X PCT</b>
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20. The following fees are submitted:				<b>CALCULATIONS PTO USE ONLY</b>	
<b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5) ) :</b>					
<input type="checkbox"/> Search Report has been prepared by the EPO or JPO .....	<b>\$840.00</b>				
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) .....	<b>\$670.00</b>				
<input type="checkbox"/> No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) .....	<b>\$760.00</b>				
<input checked="" type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO .....	<b>\$970.00</b>				
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) .....	<b>\$96.00</b>				
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>\$970.00</b>	
Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)). <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30				<b>\$130.00</b>	
<b>CLAIMS</b>	<b>NUMBER FILED</b>	<b>NUMBER EXTRA</b>	<b>RATE</b>		
Total claims	20 - 20 =	0	x \$18.00	<b>\$0.00</b>	
Independent claims	3 - 3 =	0	x \$78.00	<b>\$0.00</b>	
Multiple Dependent Claims (check if applicable). <input type="checkbox"/>				<b>\$0.00</b>	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				<b>\$1,100.00</b>	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable). <input type="checkbox"/>				<b>\$0.00</b>	
<b>SUBTOTAL =</b>				<b>\$1,100.00</b>	
Processing fee of <b>\$130.00</b> for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)). <input type="checkbox"/> 20 <input type="checkbox"/> 30 +				<b>\$0.00</b>	
<b>TOTAL NATIONAL FEE =</b>				<b>\$1,100.00</b>	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/>				<b>\$0.00</b>	
<b>TOTAL FEES ENCLOSED =</b>				<b>\$1,100.00</b>	
				<b>Amount to be: refunded</b>	<b>\$</b>
				<b>charged</b>	<b>\$</b>


- ☒ A check in the amount of **\$1,100.00** to cover the above fees is enclosed.
- ☐ Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \_\_\_\_\_ to cover the above fees.  
A duplicate copy of this sheet is enclosed.
- ☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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**40,073**

REGISTRATION NUMBER

DATE

*May 22, 2000*

09/554884

526 Rec'd PCT/PTO 22 MAY 2000

9847-0049-6X PCT  
ENKEL 8336

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:

BERTIL LARSSON, ET AL.

: ATTN: APPLICATION DIVISION

SERIAL NO: NEW APPLICATION  
(BASED ON PCT/SE98/02162)

FILED: HERewith

FOR: A METHOD OF APPLYING A TUBE  
MEMBER IN A STATOR SLOT IN  
A ROTATING ELECTRICAL MACHINE

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS  
WASHINGTON, DC 20231

SIR:

Prior to examination on the merits, please amend the above-identified patent application  
as follows:

IN THE SUBSTITUTE SPECIFICATION

Page 3, line 28, change "10-1 - 106" to --10<sup>-1</sup> - 10<sup>6</sup>--.

IN THE CLAIMS

Please cancel without prejudice or disclaimer Claims 1-19.

Please add new Claims 20-39 as follows:

--20. A method for mounting a tube in a space in a rotating electric machine defined by a restricting area having a shape corresponding to a shape of the tube comprising the steps of:

inserting the tube into the space;

pressurizing the tube with a hot pressure medium having a temperature that causes the tube to soften and expand until an outer periphery of the tube assumes the shape of the restricting area of the space; and

substituting a cold pressure medium for the hot pressure medium while maintaining a pressure constant to the pressure used in the pressurizing step causing the tube to solidify and permanently assume an expanded shape.

21. The method of Claim 20, wherein the tube being at least one of a cooling tube and a spacer between windings in a stator tooth slot.

22. The method of Claim 20, wherein the pressurizing step comprises allowing the tube to expand until 50% of an original wall thickness of the tube remains.

23. A rotating electric machine, comprising:

a stator including a stator yolk and stator slots separated by stator teeth extending inwardly from the stator yolk and having an undulated side and a flat side;

stator cable windings of an insulated cable configured to fit into concave portions of the undulated side of the stator slots and form spaces between the insulated cable windings and the flat side of the stator teeth, the spaces extending axially through the stator; and

at least one tube made of a dielectric material mounted in the stator slots so as to fill the spaces between the insulated cable windings and the flat side of the stator teeth.

24. The rotating electric machine of Claim 23, wherein:

the at least one tube being made of a polymer material.

25. The rotating electric machine of Claim 23, wherein:

the at least one tube being made of high-density polyethylene.

26. The rotating electric machine of Claim 23, wherein:

the at least one tube being made of cross-linked polyethylene.

27. The rotating electric machine of Claim 23, wherein:

the spaces are triangular; and

the at least one tube being triangular.

28. The rotating electric machine of Claim 23, wherein:

all spaces in the stator slots are filled with the at least one tube.

29. The rotating electric machine of Claim 23, wherein:

the insulated cable comprises

a high-voltage cable that includes

a conductor having a plurality of strands,

an inner semiconducting layer disposed around the conductor,

an insulating layer disposed around the inner semiconducting layer, and

an outer semiconducting layer disposed around the insulating layer.

30. The rotating electric machine of Claim 29, wherein:

the high-voltage cable having a diameter in a range of 20-250 millimeters (mm) and a conducting area in a range of 80-3000 mm<sup>2</sup>.

31. The rotating electric machine of Claim 29, wherein:

the high-voltage cable being flexible.

32. The rotating electric machine of Claim 31, wherein:

the layers of the high-voltage cable being configured to adhere to one another when bent.

33. The rotating electric machine of Claim 29, wherein:

at least one pair of the inner semiconducting layer and the insulating layer, and the insulating layer and the outer semiconducting layer of the high-voltage cable having a substantially same coefficient of thermal expansion.

34. The rotating electric machine of Claim 31, wherein:

the insulating layer comprises a solid material; and,

the respective layers of the high-voltage cable are configured to adhere to each other.

35. The rotating electric machine of Claim 29, wherein:

the respective layers of the high-voltage cable comprise materials having an elasticity and coefficients of thermal expansion such that a volume change of the respective layers due to

temperature variations being absorbed by the elasticity of the materials and the respective layers remain in contact with each other over an operating temperature range.

36. The rotating electric machine of Claim 29, wherein:

the respective layers of the high-voltage cable comprise materials having a high elasticity.

37. The rotating electric machine of Claim 29, wherein:

each of the respective layers of the high-voltage cable comprise materials having substantially same coefficients of thermal expansion.

38. The rotating electric machine of Claim 29, wherein:

the inner semiconducting layer and the outer semiconducting layer each being configured to constitute a substantially equipotential surface.

39. An apparatus for mounting a tube in a space of a rotating electric machine defined by a restricting area having a shape corresponding to a shape of the tube comprising:

means for inserting the tube into the space;

means for pressurizing the tube with a hot pressure medium having a temperature that causes the tube to soften and expand until an outer periphery of the tube assumes the shape of the restricting area of the space; and

means for substituting a cold pressure medium for the hot pressure medium while maintaining a pressure constant to the pressure used in the pressurizing step causing the tube to solidify and permanently assume an expanded shape.--

IN THE ABSTRACT OF THE DISCLOSURE

After the last page of the specification, please insert the following Abstract of the Disclosure.



--ABSTRACT OF THE DISCLOSURE

A method for mounting a tube in a space having a shape corresponding to the shape of the tube. The tube is inserted into the space, pressurized with a hot pressure medium causing the tube to expand until the space is filled, then a cold pressure medium is substituted for the hot pressure medium while maintaining constant pressure causing the tube to solidify in its expanded shape. Also, a rotating electric machine having such a tube between windings of a high-voltage cable in a stator slot.--

## REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested. Claims 20-39 are pending, Claims 1-19 having been canceled without prejudice or disclaimer and Claims 20-39 having been added by way of the present amendment. New Claims 20-39 find support in original Claims 1-19, and thus add no new matter. An Abstract has been added, consistent with U.S. patent drafting procedure.

Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a substitute specification is filed herewith in addition to a marked-up copy of the original application. Please enter this substitute specification. To the extent any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes should be construed as typographical errors and the language included in the originally-filed PCT application should be construed as containing the controlling language.

The Substitute Specification has been amended to correct a typographical error that was included in the originally-filed PCT application. Consistent with our duty of candor, we note that this amendment was not authorized by the International Searching Authority (ISA) during the international phase of the application since the change was not considered to comply with the requirements of PCT Rule 91.1(b). It is respectfully submitted that because the examples provided within the same sentence as the typographical error (“e.g. 1-500 ohm-cm, or 10-200 ohm-cm,” see Substitute Specification, page 3, lines 28-29) provide ranges that fall outside of the range as read with the error (“10-1 – 106 ohm cm,” see Substitute Specification, page 3, line 28), this is clearly a typographical error. Furthermore, it would be clear to one of ordinary skill in the art, who is also familiar with word processing software,

that when describing a single range of semiconducting resistivity values that the expression “ $10^{-1} - 10^6$  ohm-cm” can only make sense when read as “ $10^{-1} - 10^6$  ohm-cm.” The two expressions contain exactly the same character strings. The only difference between the two from a typographical perspective is specifying the  $-1$  and the  $6$  as superscripts to indicate the appropriate powers of  $10$ , a common typographical informality. Accordingly, it is respectfully requested that this amendment to the Substitution Specification be entered.

The present document is one of a set of patent applications containing related technology as was discussed in “response to petition under 37 C.F.R. §1.182 seeking special treatment relating to an electronic search tool, and decision on petition under 37 C.F.R. §1.183 seeking waiver of requirements under 37 C.F.R. §1.98,” filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an Information Disclosure Statement is filed herewith including a PTO Form 1449 with references that are included as part of the specially-created official digest in class 174. It is believed that submission of these materials and the reference to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with the decision.

In view of the present amendment and in light of the foregoing comments, an examination on the merits is believed to be in order and an early and favorable action is respectfully requested.

Respectfully submitted,

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## SUBSTITUTE SPECIFICATION

9847-0049-6X PCT  
ENKEL 8336

5

TITLE OF THE INVENTION

A METHOD OF APPLYING A TUBE MEMBER IN A STATOR SLOT  
IN A ROTATING ELECTRICAL MACHINE

10

BACKGROUND OF THE INVENTIONField of the Invention

The present invention relates to rotating electric machines such as synchronous machines. It also relates to double-fed machines, applications in asynchronous static current converter cascades, external pole machines and synchronous flux machines, as well as to alternating current machines intended primarily as generators in a power station for generating electric power. The invention particularly relates to the stator in such machines and a method for fixing the windings, as well as cooling the stator teeth and the insulated electric conductor constituting the stator winding.

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Discussion of the Background

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Similar machines have conventionally been designed for voltages in the range 15-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, which is in the range of approximately 130-400 kV. The present invention is intended primarily for use with high voltages. High voltages shall be understood here to mean voltages in excess of 10 kV. A typical operating range for the machine according to the invention may be voltages from 36 kV up to 800 kV. The invention is secondarily intended for use in the stated technical area at voltages below 36 kV.

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Two different air-cooled systems exist for conventional cooling: radial cooling where the air passes the rotor through the hub and radial channels in the rotor, and axial cooling where the air is blown into the pole gaps by axial fans. The stator is divided into radial air ducts created by (often straight) spacers that are welded in place. Due to the poor thermal conductivity axially through the stator laminations the air ducts must be frequently repeated. The drawback with air-cooling is that the ventilation losses are considerable and that, because of the ventilation ducts, the stator becomes longer. Furthermore, particularly with said high-

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voltage generators with long teeth, the ventilation ducts may also weaken the structure mechanically.

Axial liquid cooling, e.g. water-cooling, through cooling tubes, e.g. of metal, in the stator yoke has been known for some time. One drawback is that eddy currents are induced in metal tubes if they are present in a magnetic flux varying with time, thus leading to certain power losses when used in an electric machine.

### SUMMARY OF THE INVENTION

The object of the present invention is to provide a method for mounting a cooling tube in a cooling tube channel, and also a rotating electric machine having cooling tubes mounted using this method in conjunction with direct cooling of the stator and particularly the stator teeth in such a machine.

Another object of the invention is to eliminate ventilation ducts, thereby resulting in shorter and stronger stators, at the same time as ensuring that the magnetic flux in the stator teeth is disturbed as little as possible by said cooling. The object is also to achieve a higher degree of efficiency.

A further object of the invention is to achieve a steady fixing of the cables in the stator slots by these cooling tubes.

The above-mentioned object is achieved by the method and the arrangement in accordance with the invention having the features described herein.

By using high-voltage insulated electric conductors with solid insulation similar to that used in cables for transmitting electric power (e.g. XLPE-cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional transformer can thus be eliminated.

The concept generally requires the slots in which the cables are placed in the stator to be deeper than with conventional technology (thicker insulation due to higher voltage and more turns in the winding). This means that the distribution of losses differs from that in a conventional machine, which in turn entails new problems in cooling the stator, for instance, and particularly the stator teeth.

The insulated conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like, those currently used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable has an inner conductor composed of one or more strand parts, an inner semiconducting layer  
5 surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from conductors which are bent during assembly. The flexibility of a XLPE-cable normally  
10 corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer is made of cross-linked, low-density  
15 polyethylene, and the semiconducting layers are made of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being  
20 lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a resistivity within the range of  $10^{-1}$  -  $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

30 The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at

least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but at the same time sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention relates to a method for fixing the cable in a high-voltage generator by a pre-shaped triangular tube of XLPE that during operation is to also used for cooling the windings and the tooth section of the stator core. At the assembly, the pre-shaped tube is inserted into the triangular space between cables and tooth. The shape of the tube should provide enough clearance to permit easy insertion of the tube. When the tube is in place, it is heated to a temperature of 125-130 C at which it may be shaped. Moreover, an over-pressure is applied to the inside of the tube in order to press the tube against the cables and the slot wall. Both heating and pressurizing of the tube are achieved by heating and pressurizing a



pressure medium, causing the tube to soften and expand, whereby its outer periphery assumes a shape fitting against cables and slot wall. While retaining the overpressure, the tube is then cooled by exchanging the warm pressure medium against a cold pressure medium, e.g. cold water, which fills the expanded tube and causes it to solidify and permanently assume this expanded shape. The tube will now act as an elastic element, absorbing the thermal expansion of the cables during operation. The tube is also used as a cooling tube during operation, the overpressure of the cooling medium providing a steadying pressure on the cables. This pressure against cables and the slot wall improves the heat transfer as well. The tubes are placed against one of the slot walls in every or every other cable interspace.

The invention also relates to a rotating electric machine provided with cooling tubes that can also fix the position of the cable that are mounted by this method.

The machine has axially running cooling tubes made of a dielectric material, e.g. a polymer, and drawn through the triangular cable interspaces in the stator teeth. The tubes are expanded in the interspaces so that good heat transfer occurs when coolant is circulated in the tubes. The tubes run in the stator yoke and in the stator teeth along the entire axial length of the stator and, if necessary, they can be spliced in the stator teeth.

Polymer cooling tubes are non-conducting and the risk of short-circuiting is therefore eliminated, nor can eddy currents occur in them. Polymer cooling tubes can also be bent cold and drawn through several cooling tube channels without splicing, which is a great advantage.

Polymer cooling tubes can be produced from many materials, such as polyethylene, polypropene, polybutene, polyvinylidene fluoride, polytetrafluoroethylene, as well as filled and reinforced elastomers. Of these materials, polyethylene with high density, HDPE, is preferred since its thermal conductivity increases with increased density. If the polyethylene is cross-linked, which can be achieved by splitting a peroxide, silane cross-linking or radiation patterning, its ability to withstand pressure at increased temperature is enhanced, at the same time as the risk of voltage corrosion disappears. Cross-linked polyethylene, e.g. XLPE tubing from Wirsbo bruks AB, is used, for instance, for water pipes.

In a method and a device in accordance with the invention, the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable has an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible,

which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is drawn back and forth in a plurality of turns, i.e. without being spliced at the coil ends as required when the winding in the core consists of rigid conductors. The flexibility of a XLPE-cable  
5 normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of eight to twenty-five times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and  
10 when it is subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer is made of cross-linked, low-density polyethylene, and the semiconducting layers are made of polyethylene with soot and metal particles mixed in.  
15 Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples.  
20 Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a conductivity within the range of 1-105 ohm-cm, and being insulating respectively, i.e. with a conductivity less than 105 ohm-cm.

For example, the insulating layer may be made of a solid thermoplastic material such as low density polyethylene (LDPE), high density polyethylene (HDPE),  
25 polypropylene (PP), polybutylene (PB), polymethyl-pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene-propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

30 The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have an elasticity which is sufficient to absorb minor differences between the coefficients of thermal expansion for the materials in the layers in the radial direction of the elasticity, so that no cracks or other damage appear, and so that the layers are not released from each other.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. At the same time, the conductivity is so small that the outer semiconducting layer has sufficient resistivity to contain the electrical field in the cable.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail with reference designations as in the accompanying drawings.

Figure 1 shows schematically a perspective view of a section diagonally through the stator of a rotating electric machine;

Figure 2 shows a cross section through a high-voltage cable in accordance with the present invention;

Figure 3 shows schematically a sector of a rotating electric machine;

Figure 4 shows a cross section through part of the sector shown in Fig. 3 where the cross section is marked by a rectangle.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows part of an electric machine in which the rotor has been removed to reveal more clearly how a stator 1 is arranged. The main parts of the stator 1 include a stator

frame 2, a stator core 3 having stator teeth 4 and a stator yoke 5. The stator also has a stator winding 6 in the form of a high-voltage cable, placed in a space 7 shaped like a bicycle chain, see Figure 3, formed between each individual stator tooth 4. In Figure 3 the stator winding 6 is only indicated by its electric conductors. As shown in Figure 1, the stator winding 6 forms a coil-end bundle 8 on each side of the stator 1. Figure 3 also reveals that the insulation of the high-voltage cable is stepped in several dimensions depending on its radial location in the stator 1. For the sake of simplicity only one coil-end bundle is shown in Figure 1 at each end of the stator.

In large conventional machines the stator frame 2 often has a welded steel plate construction. In large machines the stator core 3, also known as the laminated core, is normally made of 0.35 mm core sheet, divided into stacks having an axial length of approximately 50 mm and separated from each other by partitions forming ventilation ducts 5 mm wide. However, in the machine described the ventilation ducts have been eliminated. In large machines each laminated stack is formed by placing sheet metal segments 9, punched to a suitable size, together to form a first layer, each subsequent layer being laid crosswise to form a complete laminated part of a stator core 3. The parts and partitions are held together by pressure brackets 10 which are pressed against pressure rings, fingers or segments, not shown. Only two pressure brackets are shown in Figure 1.

Figure 2 illustrates a cross section through a high-voltage cable 11 in accordance with the invention. The high-voltage cable 11 has a number of strand parts 12 made of copper (Cu), for instance, and having circular cross section. These strand parts 12 are arranged in the middle of the high-voltage cable 11. Around the strand parts 12 is a first semiconducting layer 13. Around the first semiconducting layer 13 is an insulating layer 14, e.g. XLPE insulation. Around the insulating layer 14 is a second semiconducting layer 15. The concept "high-voltage cable" in the present application thus does not have the outer protective sheath that normally surrounds a cable for power distribution. The high-voltage cable has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>. In the figure showing the component forming the insulated conductor or cable, the three layers are such that they adhere to each other even when the cable is bent. The shown cable is flexible and this property is retained throughout the service life of the cable.

Figure 3 shows schematically a radial sector of a machine with a sheet metal segment 9 of the stator 1 and a rotor pole 16 on the rotor 17 of the machine. It is also clear that the high-voltage cable 11 is arranged in the space 7 resembling a bicycle chain, formed between

each stator tooth 4. Space 7 is shown in the figure in the shape of a bicycle chain, though as shown in Figure 4, according to one embodiment of the present invention, one side of the slot is entirely flat.

Figure 4 shows four cable parts 18 of the high-voltage cable 11, which to parts are fitted into an asymmetric stator tooth slot 20 having an undulated side 21 in order to fit against the cable parts and a flat side 22. This shape of the stator tooth slots 20 results in triangular spaces 23 between each cable part 18. In each or in some of these spaces 23, tube members 24 are placed having been preshaped to correspond to the shape of space 23, though of a lesser dimension in order to permit easy insertion into the space 23. The term "tube member" designates in the following both the members function as "cooling tube" as well as fixing the position of the cable.

The tube member 24 is inserted into the space 23 and a pressure medium is heated pressurizing the tube member 24 which will soften and expand, its outer periphery assuming the shape of the restricting area of space 23 delimited by the cable parts second semiconducting layer 15 and the flat side 22 of the stator tooth slot 20, whereafter, maintaining a constant pressure, the warm pressure medium is substituted by a cold pressure medium filling the expanded tube member 24 and causing it to solidify and permanently assuming this expanded shape. It is possible to use the same pressure medium, though at different temperatures. In that case, the temperature of the warm pressure medium will be higher than the softening temperature of the tube member while the temperature of the cold pressure medium will keep below the softening temperature of the tube member. In order to prevent expansion of the free parts of the tube member, i.e. the parts situated outside the stator, these parts are provided with an expansion guard before the pressurization of the cooling tube is started.

Each tube member 24 is made of a dielectric material, e.g. a polymer, preferably XLPE, in order to prevent electric contact with the plate of the stator tooth 4 or with the second semiconducting layer 15 of the cable parts 18.

During expansion the wall thickness of tube member 24 is reduced. The tube member 24 is allowed to expand until 50 % of its original wall thickness  $G$  remains. The wall thickness and other properties of the tube member are chosen in order to ensure that, after being expanded, the remaining wall thickness is sufficient to completely fill out the space between the outer periphery of the tube member and the second semiconducting layer 15 of the cable parts and the flat side 22 of the stator tooth slot respectively. The material of the

tube member is determined with respect to factors like coefficient of thermal conductivity, coefficient of linear expansion as well as hot forming property.

Although the described embodiment relates to a triangular cable interspace, other forms of interspaces are possible, e.g. the cables may be arranged at a larger radial distance thereby forming a hour-glass-shaped interspace in which a pre-shaped cooling tube/fixing means of hour-glass shape may be arranged according to the present invention. It is also possible that the tube member prior to being expanded presents a different cross section than the space itself, e.g. an elliptic cross section, but that the tube member has a wall thickness allowing sufficient expansion.

## CLAIMS

1. A method for mounting a tube means (24) in a space (23) having a shape corresponding to the shape of the tube means (24), characterized in that the tube means (24) is inserted into the space (23) situated in a stator tooth slot (20) of a stator (1) of a rotating electric machine, having windings of high-voltage cable (11), after which a pressure medium is heated and pressurizes the tube means (24) so that this softens and expands, its outer periphery assuming the shape of the restricting area of space (23), after which the hot pressure medium is replaced with or converted to a cold pressure medium which fills out the expanded tube means (24) and causes it to solidify and permanently assume this expanded shape, whereupon the tube means (24) is used as a cooling tube.

2. A method as claimed in claim 1, characterized in that the tube means (24) acts as a cooling tube on one hand and as a fixing means for the high-voltage cable (11) on the other hand.

3. A method as claimed in any of claims 1-2, characterized in that the tube means (24) is allowed to expanded until 50% remains of its original wall thickness.

4. A rotating electric machine with at least one tube means (24) mounted according to the method as claimed in any of claims 2-3, characterized in that the stator is provided with stator teeth (4) extending inwardly from a stator yoke (5), which teeth between each other form stator teeth slots (20), in which stator windings (6) are provided, and in that the slots (20) are provided with at least one tube means (24) made of dielectric material, each inserted into a space (23) extending substantially axially through the stator and formed between cable parts (1 8) and an even side (22) provided in the stator tooth slot (20).

5. A machine as claimed in claim 4, characterized in that the tube means (24) is made of polymer material.

6. A machine as claimed in claim 4, characterized in that the tube means (24) is made of high-density polyethylene (HDPE).

7. A machine as claimed in claim 4, characterized in that the tube means (24) is made of cross-linked polyethylene (XLPE).

8. A machine as claimed in any of claims 4-7, characterized in that the space (23) is triangular and that also the tube means (24) is triangular.

9. A machine as claimed in claim 8, characterized in that tube means (24) are arranged in all spaces (23) in a stator tooth slot (20).

10. A machine as claimed in any of claims 8-9, characterized in that the high-voltage cable (11) is of a kind which comprises a conductor having of a plurality of strand parts (12), an inner semiconducting layer (13) enclosing the conductor, an insulating layer (14) enclosing the inner semiconducting layer, and an outer semiconducting layer (15) enclosing the insulating layer.

11. A machine as claimed in claim 10, characterized in that the high-voltage cable (11) has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>.

12. A machine as claimed in any of claims 4-11, characterized in that said insulated conductor or high-voltage cable (11) is flexible.

13. A machine as claimed in claim 12, characterized in that said layers (8, 9, 10) are arranged to adhere to each another even when the insulated conductor or high-voltage cable (11) is bent.

14. A machine as claimed in any of claims 4-13, characterized in that at least two adjacent layers (13,14,15) of the machine winding have substantially the same coefficients of thermal expansion.

15. A machine as claimed in any of claims 4-14, characterized in that the winding is flexible and comprises an current conducting core surrounded by an inner semiconducting layer enclosing the core, an insulating layer of solid material enclosing the inner



semiconducting layer, and an outer semiconducting layer enclosing the insulating layer, said layers adhering to each other.

16. A machine as claimed in any of claims 4-15, characterized in that said layers are made of materials having such an elasticity and such a relation between their coefficients of thermal expansion that the volume changes of the layers caused by temperature variations during operation can be absorbed by the elasticity of the material so that the layers maintain their contact with each other at the temperature variations occurring during operation.

17. A machine as claimed in any of claims 4-16, characterized in that the materials used in said layers are of high elasticity.

18. A machine as claimed in any of claims 4-17, characterized in that the coefficients of thermal expansion for the materials in said layers are substantially the same.

19. A machine as claimed in any of claims 4-18, characterized in that each of the semiconducting layers is arranged to constitute a substantially equipotential surface.

**A METHOD OF APPLYING A TUBE MEMBER IN A STATOR SLOT  
IN A ROTATING ELECTRICAL MACHINE**

**Technical field**

5 The present invention relates to rotating electric machines such as synchronous machines. It also relates to double-fed machines, applications in asynchronous static current converter cascades, external pole machines and synchronous flux machines, as well as to alternating current machines intended primarily as generators in a power station for generating electric power. The invention particularly relates to the stator in such machines and a method for fixing the windings, as well as cooling the stator teeth and the insulated electric conductor constituting the stator winding.

**Background art**

15 Similar machines have conventionally been designed for voltages in the range 15-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, which is in the range of approximately 130-400 kV. The present invention is intended primarily for use with high voltages. High voltages shall be understood here to mean voltages in excess of 10 kV. A typical operating range for the machine according to the invention may be voltages from 36 kV up to 800 kV. The invention is secondarily intended for use in the stated technical area at voltages below 36 kV.

25 Two different air-cooled systems exist for conventional cooling: radial cooling where the air passes the rotor through the hub and radial channels in the rotor, and axial cooling where the air is blown into the pole gaps by axial fans. The stator is divided into radial air ducts created by means of (often straight) spacers that are welded in place. Due to the poor thermal conductivity axially through the stator laminations the air ducts must be frequently repeated. The drawback with  
30 air-cooling is that the ventilation losses are considerable and that, because of the ventilation ducts, the stator becomes longer. Furthermore, particularly with said

high-voltage generators with long teeth, the ventilation ducts may also weaken the structure mechanically.

Axial liquid cooling, e.g. water-cooling, by means of cooling tubes, e.g. of metal, in the stator yoke has been known for some time. One drawback is that eddy currents are induced in metal tubes if they are present in a magnetic flux varying with time, thus leading to certain power losses when used in an electric machine.

### Object of the invention

The object of the present invention is to provide a method for mounting a cooling tube in a cooling tube channel, and also a rotating electric machine comprising cooling tubes mounted using this method in conjunction with direct cooling of the stator and particularly the stator teeth in such a machine.

Another object of the invention is to eliminate ventilation ducts, thereby resulting in shorter and stronger stators, at the same time as ensuring that the magnetic flux in the stator teeth is disturbed as little as possible by said cooling. The object is also to achieve a higher degree of efficiency.

A further object of the invention is to achieve a steady fixing of the cables in the stator slots by means of these cooling tubes.

### Summary of the invention

The above-mentioned object is achieved by the method and the arrangement in accordance with the invention having the features defined in the appended claims.

By using high-voltage insulated electric conductors with solid insulation similar to that used in cables for transmitting electric power (e.g. XLPE-cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The conventional transformer can thus be eliminated. The concept generally requires the slots in which the cables are placed in the stator to be deeper than with conventional technology (thicker insulation due to higher voltage and more turns in the winding). This means that the distribution of losses differs from that in a conventional

machine, which in turn entails new problems in cooling the stator, for instance, and particularly the stator teeth.

The insulated conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and  
5 WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XLPE-cables or cables with  
10 EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which\*the winding is formed from  
15 conductors which are bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate  
20 that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative  
25 coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight  
30 difference between the coefficients of thermal expansion in the layers in relation

to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a resistivity within the range of  $10^{-1}$  -  $10^6$  ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but

at the same time sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially  
5 enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention relates to a method for fixing the cable in a high-voltage generator by means of a pre-shaped triangular tube of XLPE that during operation is  
10 also used for cooling the windings and the tooth section of the stator core. At the assembly, the pre-shaped tube is inserted into the triangular space between cables and tooth. The shape of the tube should provide enough clearance to permit easy insertion of the tube. When the tube is in place, it is heated to a temperature of 125-130°C at which it may be shaped. Moreover, an overpressure is applied to  
15 the inside of the tube in order to press the tube against the cables and the slot wall. Both heating and pressurising of the tube are achieved by heating and pressurising a pressure medium, causing the tube to soften and expand, whereby its outer periphery assumes a shape fitting against cables and slot wall. While retaining the overpressure, the tube is then cooled by exchanging the warm pressure medium against a cold pressure medium, e.g. cold water, which fills the expanded tube and causes it to solidify and permanently assume this expanded  
20 shape. The tube will now act as an elastic element, absorbing the thermal expansion of the cables during operation. The tube is also used as a cooling tube during operation, the overpressure of the cooling medium providing a steadying pressure on the cables. This pressure against cables and the slot wall improves the heat  
25 transfer as well. The tubes are placed against one of the slot walls in every or every other cable interspace.

The invention also relates to a rotating electric machine provided with cooling tubes/fixing means mounted by this method.

30 The machine comprises axially running cooling tubes made of a dielectric material, e.g. a polymer, and drawn through the triangular cable interspaces in the stator teeth. The tubes are expanded in the interspaces so that good heat transfer

occurs when coolant is circulated in the tubes. The tubes run in the stator yoke and in the stator teeth along the entire axial length of the stator and, if necessary, they can be spliced in the stator teeth.

Polymer cooling tubes are non-conducting and the risk of short-circuiting is therefore eliminated, nor can eddy currents occur in them. Polymer cooling tubes can also be bent cold and drawn through several cooling tube channels without splicing, which is a great advantage.

Polymer cooling tubes can be produced from many materials, such as polyethylene, polypropene, polybutene, polyvinylidene fluoride, polytetrafluoroethylene, as well as filled and reinforced elastomers. Of these materials, polyethylene with high density, HDPE, is preferred since its thermal conductivity increases with increased density. If the polyethylene is cross-linked, which can be achieved by splitting a peroxide, silane cross-linking or radiation patterning, its ability to withstand pressure at increased temperature is enhanced, at the same time as the risk of voltage corrosion disappears. Cross-linked polyethylene, e.g. XLPE tubing from Wirsbo bruks AB, is used, for instance, for water pipes.

In a method and a device in accordance with the invention, the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is drawn back and forth in a plurality of turns, i.e. without being spliced at the coil ends as required when the winding in the core consists of rigid conductors. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of eight to twenty-five times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having a conductivity within the range of  $1-10^5$  ohm-cm, and being insulating respectively, i.e. with a conductivity less than  $10^5$  ohm-cm.

For example, the insulating layer may consist of a solid thermoplastic material such as low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl-pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene-propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylmp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.



Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have an elasticity which is sufficient to absorb  
5 minor differences between the coefficients of thermal expansion for the materials in the layers in the radial direction of the elasticity, so that no cracks or other damage appear, and so that the layers are not released from each other.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. At the same time, the conductivity is  
10 so small that the outer semiconducting layer has sufficient resistivity to contain the electrical field in the cable.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding composed of these layers will substantially enclose the electrical field within it.

15 There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

#### Brief description of the drawings

The invention will now be described in more detail with reference designations as in the accompanying drawings.  
20

Figure 1 shows schematically a perspective view of a section diagonally through the stator of a rotating electric machine;

Figure 2 shows a cross section through a high-voltage cable in accordance with the present invention;

25 Figure 3 shows schematically a sector of a rotating electric machine;

Figure 4 shows a cross section through part of the sector shown in Fig. 3 where the cross section is marked by a rectangle.

#### Description of the invention

30 Figure 1 shows part of an electric machine in which the rotor has been removed to reveal more clearly how a stator 1 is arranged. The main parts of the stator 1 consist of a stator frame 2, a stator core 3 comprising stator teeth 4 and a

stator yoke 5. The stator also comprises a stator winding 6 in the form of a high-voltage cable, placed in a space 7 shaped like a bicycle chain, see Figure 3, formed between each individual stator tooth 4. In Figure 3 the stator winding 6 is only indicated by its electric conductors. As shown in Figure 1, the stator winding 6 forms a coil-end bundle 8 on each side of the stator 1. Figure 3 also reveals that the insulation of the high-voltage cable is stepped in several dimensions depending on its radial location in the stator 1. For the sake of simplicity only one coil-end bundle is shown in Figure 1 at each end of the stator.

In large conventional machines the stator frame 2 often consists of a welded steel plate construction. In large machines the stator core 3, also known as the laminated core, is normally made of 0.35 mm core sheet, divided into stacks having an axial length of approximately 50 mm and separated from each other by partitions forming ventilation ducts 5 mm wide. However, in the machine described the ventilation ducts have been eliminated. In large machines each laminated stack is formed by placing sheet metal segments 9, punched to a suitable size, together to form a first layer, each subsequent layer being laid cross-wise to form a complete laminated part of a stator core 3. The parts and partitions are held together by pressure brackets 10 which are pressed against pressure rings, fingers or segments, not shown. Only two pressure brackets are shown in Figure 1.

Figure 2 illustrates a cross section through a high-voltage cable 11 in accordance with the invention. The high-voltage cable 11 comprises a number of strand parts 12 made of copper (Cu), for instance, and having circular cross section. These strand parts 12 are arranged in the middle of the high-voltage cable 11. Around the strand parts 12 is a first semiconducting layer 13. Around the first semiconducting layer 13 is an insulating layer 14, e.g. XLPE insulation. Around the insulating layer 14 is a second semiconducting layer 15. The concept "high-voltage cable" in the present application thus does not comprise the outer protective sheath that normally surrounds a cable for power distribution. The high-voltage cable has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>. In the figure showing the component forming the insulated conductor or cable, the three layers are such that they adhere to each

other even when the cable is bent. The shown cable is flexible and this property is retained throughout the service life of the cable.

Figure 3 shows schematically a radial sector of a machine with a sheet metal segment 9 of the stator 1 and a rotor pole 16 on the rotor 17 of the machine. It is also clear that the high-voltage cable 11 is arranged in the space 7 resembling a bicycle chain, formed between each stator tooth 4. Space 7 is shown in the figure in the shape of a bicycle chain, though as shown in Figure 4, according to one embodiment of the present invention, one side of the slot is entirely flat.

Figure 4 shows four cable parts 18 of the high-voltage cable 11, which parts are fitted into an asymmetric stator tooth slot 20 having an undulated side 21 in order to fit against the cable parts and a flat side 22. This shape of the stator tooth slots 20 results in triangular spaces 23 between each cable part 18. In each or in some of these spaces 23, tube members 24 are placed having been pre-shaped to correspond to the shape of space 23, though of a lesser dimension in order to permit easy insertion into the space 23. The term "tube member" designates in the following both the member's function as "cooling tube" and as a "fixing means".

The tube member 24 is inserted into the space 23 and a pressure medium is heated pressurising the tube member 24 which will soften and expand, its outer periphery assuming the shape of the restricting area of space 23 delimited by the cable parts second semiconducting layer 15 and the flat side 22 of the stator tooth slot 20, whereafter, maintaining a constant pressure, the warm pressure medium is substituted by a cold pressure medium filling the expanded tube member 24 and causing it to solidify and permanently assuming this expanded shape. It is possible to use the same pressure medium, though at different temperatures. In that case, the temperature of the warm pressure medium will be higher than the softening temperature of the tube member while the temperature of the cold pressure medium will keep below the softening temperature of the tube member. In order to prevent expansion of the free parts of the tube member, i.e. the parts situated outside the stator, these parts are provided with an expansion guard before the pressurisation of the cooling tube is started.

Each tube member 24 is made of a dielectric material, e.g. a polymer, preferably XLPE, in order to prevent electric contact with the plate of the stator tooth 4 or with the second semiconducting layer 15 of the cable parts 18.

During expansion the wall thickness of tube member 24 is reduced. The tube member 24 is allowed to expand until 50 % of its original wall thickness G remains. The wall thickness and other properties of the tube member are chosen in order to ensure that, after being expanded, the remaining wall thickness is sufficient to completely fill out the space between the outer periphery of the tube member and the second semiconducting layer 15 of the cable parts and the flat side 22 of the stator tooth slot respectively. The material of the tube member is determined with respect to factors like coefficient of thermal conductivity, coefficient of linear expansion as well as hot forming property.

Although the described embodiment relates to a triangular cable interspace, other forms of interspaces are possible, e.g. the cables may be arranged at a larger radial distance thereby forming a hour-glass-shaped interspace in which a pre-shaped cooling tube/fixing means of hour-glass shape may be arranged according to the present invention. It is also possible that the tube member prior to being expanded presents a different cross section than the space itself, e.g. an elliptic cross section, but that the tube member has a wall thickness allowing sufficient expansion.

## CLAIMS

1. A method for mounting a tube means (24) in a space (23) having a shape corresponding to the shape of the tube means (24), **characterized** in that the tube means (24) is inserted into the space (23) situated in a stator tooth slot (20) of a stator (1) of a rotating electric machine, having windings of high-voltage cable (11), after which a pressure medium is heated and pressurises the tube means (24) so that this softens and expands, its outer periphery assuming the shape of the restricting area of space (23), after which the hot pressure medium is replaced with or converted to a cold pressure medium which fills out the expanded tube means (24) and causes it to solidify and permanently assume this expanded shape, whereupon the tube means (24) is used as a cooling tube.
2. A method as claimed in claim 1, **characterized** in that the tube means (24) acts as a cooling tube on one hand and as a fixing means for the high-voltage cable (11) on the other hand.
3. A method as claimed in any of claims 1-2, **characterized** in that the tube means (24) is allowed to expanded until 50% remains of its original wall thickness.
4. A rotating electric machine with at least one tube means (24) mounted according to the method as claimed in any of claims 2-3, **characterized** in that the stator is provided with stator teeth (4) extending inwardly from a stator yoke (5), which teeth between each other form stator teeth slots (20), in which stator windings (6) are provided, and in that the slots (20) are provided with at least one tube means (24) made of dielectric material, each inserted into a space (23) extending substantially axially through the stator and formed between cable parts (18) and an even side (22) provided in the stator tooth slot (20).
5. A machine as claimed in claim 4, **characterized** in that the tube means (24) is made of polymer material.

6. A machine as claimed in claim 4, **characterized** in that the tube means (24) is made of high-density polyethylene (HDPE).
7. A machine as claimed in claim 4, **characterized** in that the tube means  
5 (24) is made of cross-linked polyethylene (XLPE).
8. A machine as claimed in any of claims 4-7, **characterized** in that the space (23) is triangular and that also the tube means (24) is triangular.
- 10 9. A machine as claimed in claim 8, **characterized** in that tube means (24) are arranged in all spaces (23) in a stator tooth slot (20).
10. A machine as claimed in any of claims 8-9, **characterized** in that the high-voltage cable (11) is of a kind which comprises a conductor having of a plurality of  
15 strand parts (12), an inner semiconducting layer (13) enclosing the conductor, an insulating layer (14) enclosing the inner semiconducting layer, and an outer semiconducting layer (15) enclosing the insulating layer.
11. A machine as claimed in claim 10, **characterized** in that the high-voltage  
20 cable (11) has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>.
12. A machine as claimed in any of claims 4-11, **characterized** in that said insulated conductor or high-voltage cable (11) is flexible.
- 25 13. A machine as claimed in claim 12, **characterized** in that said layers (8, 9, 10) are arranged to adhere to each another even when the insulated conductor or high-voltage cable (11) is bent.
- 30 14. A machine as claimed in any of claims 4-13, **characterized** in that at least two adjacent layers (13,14,15) of the machine winding have substantially the same coefficients of thermal expansion.

15. A machine as claimed in any of claims 4-14, **characterized** in that the winding is flexible and comprises an current conducting core surrounded by an inner semiconducting layer enclosing the core, an insulating layer of solid material  
5 enclosing the inner semiconducting layer, and an outer semiconducting layer enclosing the insulating layer, said layers adhering to each other.

16. A machine as claimed in any of claims 4-15, **characterized** in that said layers are made of materials having such an elasticity and such a relation between their coefficients of thermal expansion that the volume changes of the layers caused by temperature variations during operation can be absorbed by the elasticity of the material so that the layers maintain their contact with each other at the temperature variations occurring during operation.

17. A machine as claimed in any of claims 4-16, **characterized** in that the materials used in said layers are of high elasticity.

18. A machine as claimed in any of claims 4-17, **characterized** in that the coefficients of thermal expansion for the materials in said layers are substantially the  
20 same.

19. A machine as claimed in any of claims 4-18, **characterized** in that each of the semiconducting layers is arranged to constitute a substantially equipotential surface.

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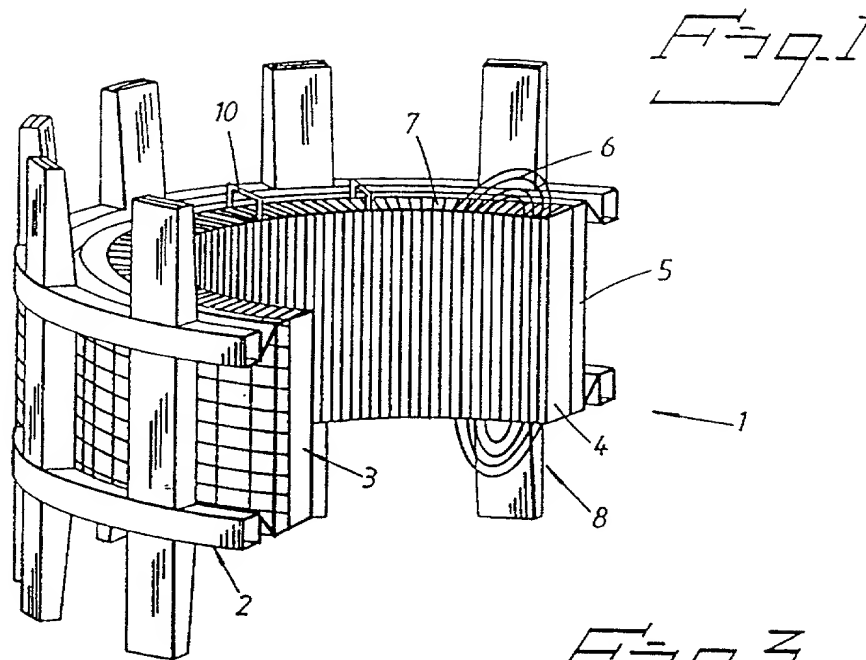
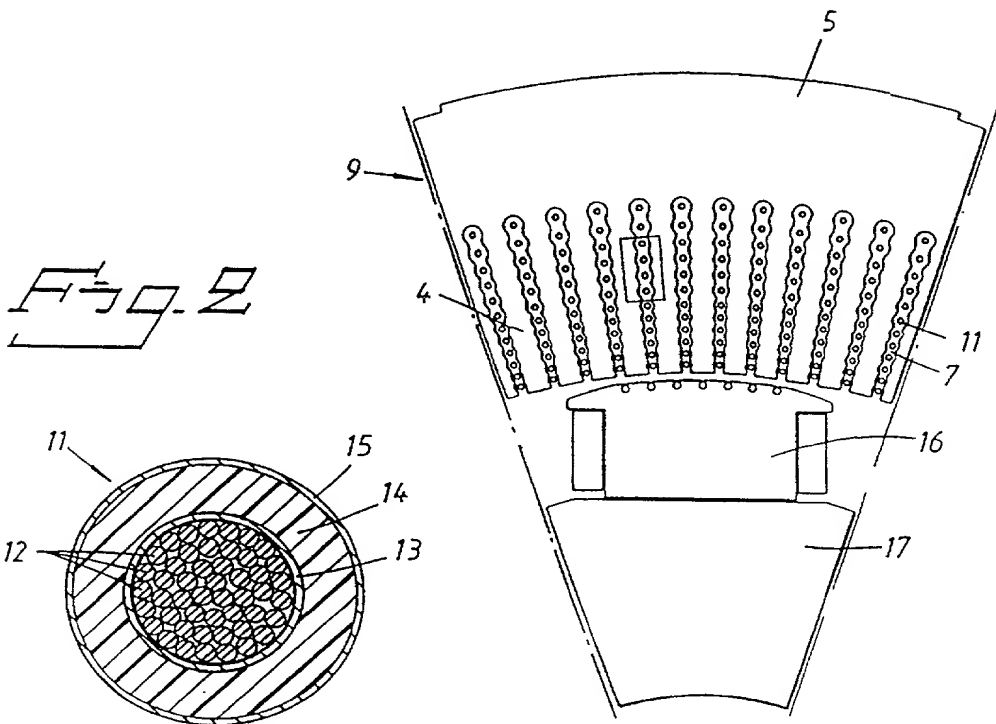


Fig. 3





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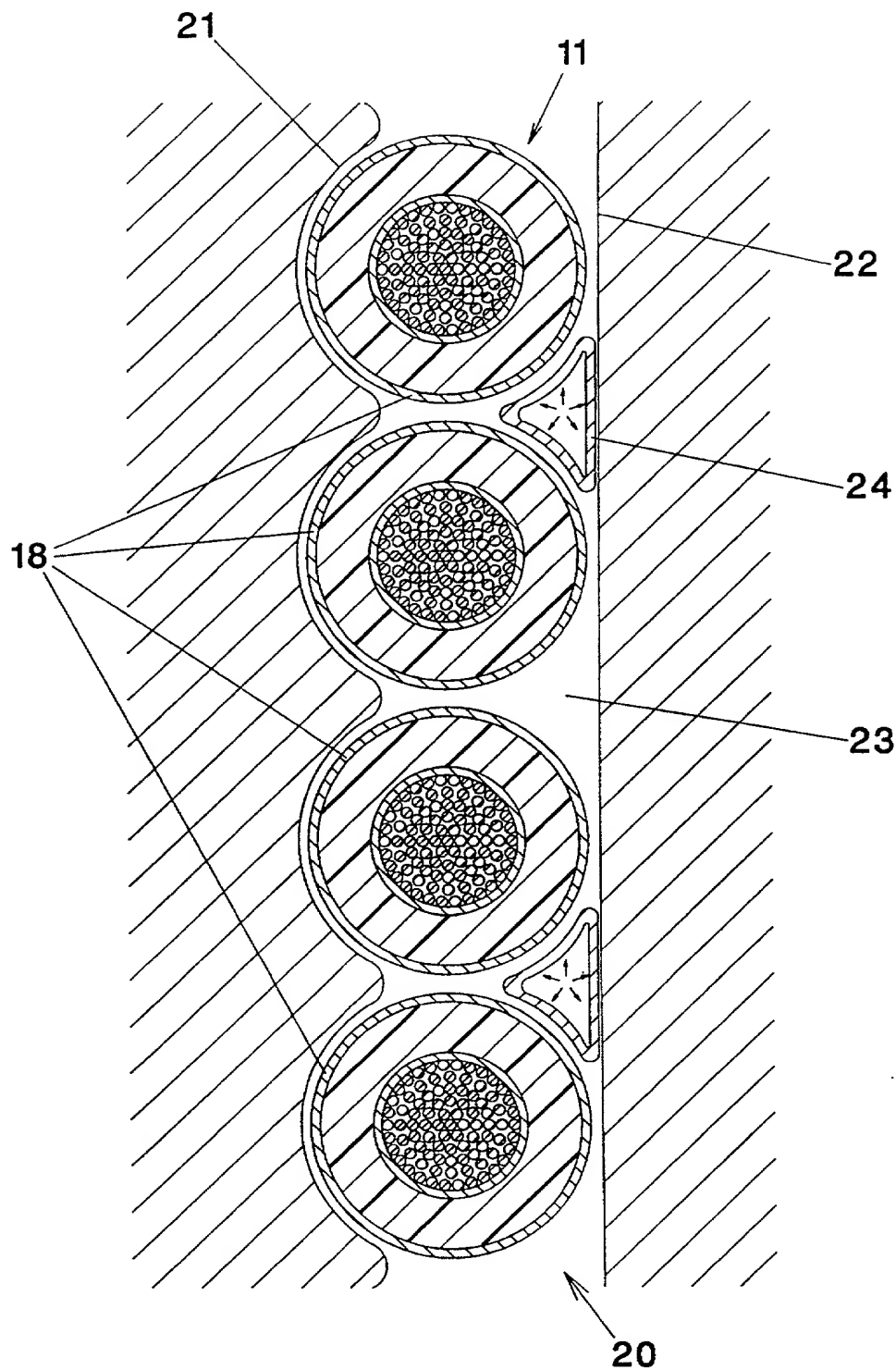


Fig 4

# Declaration, Power Of Attorney and Petition

Page 1 of 3

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

A METHOD OF APPLYING A TUBE MEMBER IN A STATOR SLOT IN A ROTATING  
ELECTRICAL MACHINE

the specification of which

☐ is attached hereto.

☒ was filed on 22 May 2000 as

Application Serial No. \_\_\_\_\_

and amended on \_\_\_\_\_.

☒ was filed as PCT international application

Number PCT/SE98/02162

on 27 November 1998,

and was amended under PCT Article 19

on \_\_\_\_\_ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed	
<u>9704380-6</u>	<u>SWEDEN</u>	<u>27 November 1997</u>	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes	<input type="checkbox"/> No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

<u>                    </u> (Application Number)	<u>                    </u> (Filing Date)
<u>                    </u> (Application Number)	<u>                    </u> (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
<u>PCT/SE98/02162</u>	<u>27 November 1998</u>	<u>                    </u>
<u>                    </u>	<u>                    </u>	<u>                    </u>
<u>                    </u>	<u>                    </u>	<u>                    </u>

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; Vincent J. Sunderdick, Reg. No. 29,004; William E. Beaumont, Reg. No. 30,996; Robert F. Gnuse, Reg. No. 27,295; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Robert W. Hahl, Reg. No. 33,893; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; Paul E. Rauch, Reg. No. 38,591; William T. Enos, Reg. No. 33,128; and Michael E. McCabe, Jr., Reg. No. 37,182; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

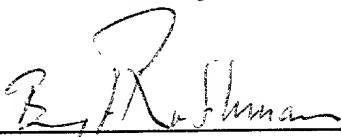
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